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14. ABSTRACT

This report results from a contract tasking University of Abertay Dundee as follows: The Grantee will investigate the cognitive processes of commanders and their staff with the intention of developing more effective technological support via agent-based technology. The research will make use of interviews, observational protocols and statistical analytic techniques to identify the conceptual structures used in developing, evaluating and monitoring command decisions. The product will be an analysis of conceptual structures explicitly and implicitly used by commanders in making battlespace decisions during planning development and execution.

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Command Transcripts: Supporting Task and Functions

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Summary

The following report considers the critical issues in supporting command-team functions, using an analysis of those tasks identified in transcripts of command-team members discussing critical incidents (Cook, Adams and Angus, 2004) and issues in command team performance. In previous research, a twelve-category framework was developed from an historical analysis of command-team performance and this was applied to the transcripts from command-team members (Cook, Adams and Angus, 2004). The more recent analysis of the framework was developed without a priori knowledge of the original framework and this produced between seven and eight major categories that embraced almost all the text units identified in the transcripts. The major categories identified in the analysis overlap significantly with the categories identified via the earlier historical analysis but the sub-nodes in each category differ, suggesting some qualified degree of validity. The current analysis would have been inadequate without prior knowledge of command team practice and opportunities to assess the validity of the conclusions using subject-matter experts. It is acknowledged that participatory design approaches are more appropriate to meet user-centred design criteria (see Wood, Webb, Cross, and Bopping, 1999) but given the limited access to command staff the adapted critical incident method used was a reasonable compromise.

The seven most significant categories identified in the current analysis included decision-making, technology, command-team issues, information-intelligence, general human factors issues and communication. The most recent analysis strongly supports the view that command teams make extensive use of socio-cognitive processing to produce effective decision-making and planning. It is argued that the introduction of technology should be carefully considered to prevent undermining these processes. Although it is recognised that the role of the socio-cognitive processes could be epiphenomenal in effective command-team decision-making and further empirical support must be provided for the assertion that socio-cognitive processes underpin effective decision-making. Empirical tests of critical issues in command-team function are proposed and considered briefly at the end of the report.

The purpose of the current report is to summarise the previous work and to consider the way in which this would support an experimental program of work to identify critical issues in knowledge management in command and control.

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Introduction

In the review of human issues in command at the NATO Conference held in 1998, which was later reviewed in the edited collection of papers by McCann and Pigeau (2000) it was suggested that a number of features were considered critical in command-team performance. The issues identified included communication (Pigeau and McCann, 2000), the use of schema-based approaches to decision-making (Paris, Johnston and Reeves, 2000; Cook, Elder, and Pascual, 1999) and formal-informal analysis procedures in command-team planning (Fallesen, 2000). These issues are in turn subject to both cognitive and social psychological factors that can make performance better or worse. The published research prior to that conference and after has largely focussed on the basic theoretical issues that would influence performance but without considering the way that the nature of the task may interact with psychological variables to produce variations in performance.

A review of issues in command and control was previously developed and presented as a case for information visualisation using a similar technique to that used in the current research (Macklin, Cook, Angus, Adams, Cook, and Cooper, 2002). Transcripts were collected and analysed to determine what the critical issues were likely to be in developing a successful visualisation strategy for supporting high level command and control, at strategic and theatre level decision making. In the analysis of the current transcripts from command teams (Cook, Angus, and Adams, 2004), support was found for a number of the high-level issues identified in Pigeau and McCann's edited collection of papers on human issues in command and control.

Communication –

Communication
Various communication elements

There is other evidence that communication skill is a critical determinant of performance in tasks related to those in command and control (Winkler, 1999).

Schema based decision-making -

Use of examples
Examples of battle procedures, plans and/or tactics

However, these issues were identified at a relatively course level of analysis and many of the sub-topics related to communication and the use of mental models raised issues that have a direct bearing on the technology used to support decision-making.

In the review of issues edited by McCann and Pigeau (2000) various factors are considered and among the most significant are the definition of the task and the

familiarity of the task. It can be argued that variations in uncertainty within the task and the level of familiarity with the specific task would radically change the way that the command team perform. Uncertainty is a critical aspect of warfighting that has persisted in the electronic information age and that influences the process of decision-making (Schmitt and Klein, 1998).

Consider the employment of schema-based or recognition primed decision-making accounts of command-team performance and the familiar-unfamiliar dimension of task type. Familiar tasks will contain cues to long-term memory that stimulate recall of material from episodic, semantic and even procedural memory that support effective decision-making. Familiarity with tasks in terms of execution is partially attributable to knowledge of results, and even where these outcomes were previously failed, this can narrow the search space for an alternative course of action. Schema-based or pattern-matching solutions to unfamiliar problems are likely to be much less effective because the unfamiliar problems do not have cues to guide memory retrieval of solutions, rules to guide the production of action sequences or any knowledge of consequences to inform the command team about the likelihood of success. It might be argued that many of the more recent conflicts are typically less familiar and more unpredictable making the process of responding more complicated and less amenable to recognition primed decision making. A full discussion of the issues relating memory and process management can be found in Cook (2001) where it is proposed that various types of memory process are fundamental to situation awareness and a case can be made for identifying memory loading as the critical quality limiting factor in effective command and control. The importance of memory is a point that had been made specifically about working memory in other work examining the impact of fatigue on working memory and command performance (Cook, Reid, and Wilson, 2001).

The decision-making process and outcomes identified by Pigeau and McCann's (2000) edited collection of papers tentatively suggests the separation of command team analysis into three pertinent domains. The two domains suitable for analysing the command-team performance are the socio-cognitive aspects of decision-making and the task-specific requirements of command-team decision-making. This document is largely intended to summarise the socio-cognitive aspects of decision-making but reference is made to task-related demands that would influence outcomes. The case for detailed analysis of cognitive activities in command and control has been made elsewhere (Persson, Nyce, and Erikson, 2000; Pigeau and McCann, 2000; Cook, 2000; Cook, Stapleton, and Artman, 2000). This acceptance of command as a socio-cognitive process within a complex socio-technical system depends on the acknowledgement of the user as the prime force shaping the services afforded by technology. Thus, the technology should be adapted to the capabilities of user, trying to accomplish tasks and this is accomplished by the completion of sub-tasks that are likely to remain unchanged. There are a number of simple philosophies that have been applied to technological support for command that run counter to this approach. In some cases it may be assumed that the user is the source of noise and reduced performance and an attempt is made to use technology to synthesise a superior decision making capability. In some cases the user is the part of the system that is assumed to be most adaptable and the relationship between the user's tasks and the system's operation are simply treated as coincidental and loosely coupled. This document assumes that system operation will shape the user's actions as part of a joint

cognitive system and that user tasks, system operation and performance are inter-related. This type of framework for analysing command team performance is similar to that developed within the sensemaking community (Leedom, 2002) where it has been acknowledged that the way that teams work on problems, the types of problems and the social and cognitive challenges of the problems are inter-related. Alberts (2002) has suggested that collaboration (interpersonal interaction), cognitive processes and sensemaking are all fundamental processes for future commanders. It is possible to relate these three topics to those identified within Pigeau and McCann's (2000) edited collection of papers. The inter-relationship of the task type and the social and cognitive challenges is underlined by recent work examining the cognitive underpinnings of team performance (Cooke, Keikel, Salas, Bowers, Stout, and Cannon-Bowers, 2003) where it was found that cross-training that improved mutual understanding of role requirements improved performance.

Multi-Layered Task Analysis of Command Function

In the analysis of the transcripts and in previous research observing command-team functions it is possible to identify explicit and implicit tasks within the team processes. Explicit tasks could for example consist of task-resource matching in the form of apportionment over a scheduled period of activity and include estimates of attrition of men and material. The process of matching would require some knowledge of enemy force disposition and force capability, in men and material. Thus, implicit in the task of apportionment is the creation of a mental model of enemy capability and battlefield disposition. This mental model may be further enhanced by the integration of intelligence reports and reviews that appear as a separate explicit task of updating the planning model. Thus, distinct explicit tasks could support implicit tasks like the mental model of enemy force and disposition that in turn improve the quantitative and qualitative accuracy of situational awareness. This is illustrated below, showing that explicit tasks frequently support completion of implicit tasks.

It should be noted that completion of implicit tasks would facilitate or support the completion of explicit tasks. For example, forming a mental model involves what is known about the situation. That known information will support the explicit task of identifying new information and gaps in the currently available information, and updating the planning model. Thus, the arrows in the figure should actually be bi-directional. In practical terms it would require ingenious experimentation, with a very artefactual design, to create conditions in which the tasks could be separately manipulated to identify the contributions from explicit and implicit tasks. A critical series of questions regarding the relationship between different tasks emerges in terms of inter-dependency between tasks and the function that describes degradation. It is possible that contributions from a specific task could relate in an all or nothing manner, such that success is required for the dependent task to take place. Or, in some cases it might be possible for gradual degradation to occur across tasks, with some degree of success in one task contributing to partial success in another.

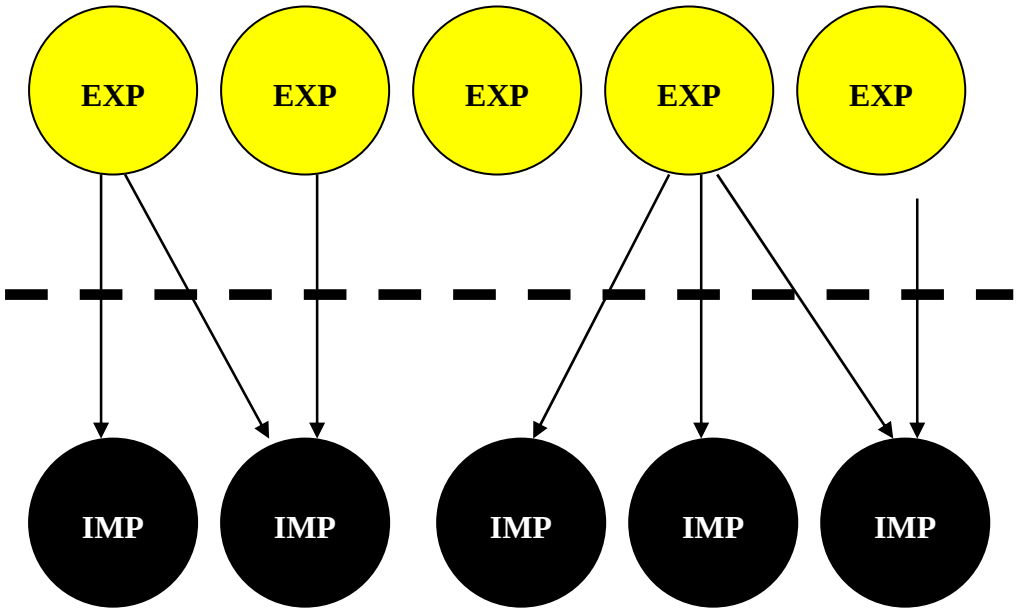

Figure 1: Explicit and Implicit Task Structure

He idea that expertise is composed of explicit and tacit knowledge and the proposal that there are explicit and implicit tasks accomplished by command teams is mutually supportive. There is a growing acceptance of the view that tacit knowledge is used in expert decision- making (Johannessen, Oaien, and Olsen, 2001) and that implicit and tacit knowledge interact (Carley and Schreiber, 2002) in a dynamic way. In addition studies have accepted that military personnel use tacit knowledge to make decisions and solve problems that are poorly defined and have a degree of uncertainty (Hedlund, Forsythe, Horvath, Williams, Snook, and Sternberg, 2003).

Shared Understanding

There were many comments on a shared understanding, a potential mental model, with possible ways in which a shared understanding can be improved upon and used.

The idea that there exist explicit and implicit tasks in command team functions is not new because Pigeau and McCann (2000) had identified this possibility in their paper on Redefining Command and Control. It can be argued that simple substitution of human and machine agents with regard to explicit tasks may undermine the completion of implicit tasks such as the creation of a shared mental-model of enemy force disposition. It is generally agreed that the construction of a shared mental-model is critical to team performance in complex command type tasks (Banks and Millward, 2000). The common use of such a strategy in automating task elements would clearly be appealing to information technologists because this would produce discrete tasks or operations that might be managed by machine intelligence. However, the

unforeseen consequences of task substitution would only appear in the operational use of the command interface.

In considering the possibility of explicit and implicit task structure and grammar a number of possibilities arise. First, it is possible to have one-to-one correspondence between explicit and implicit tasks and one may feel inclined to accept that the tasks are equivalent. However, explicit tasks may have different overt goals when compared to the implicit tasks, meaning that the goals or outcomes associated with the task contribute in different ways to overall performance. Second implicit tasks may be supported by more than a single explicit task and require completion of all tasks. Adequate performance on any individual explicit task would not be sufficient to achieve the goals and outcomes that might occur as a result of successful completion of the implicit task or performance would be graded accordingly. Thus, the mental-model of enemy intent may receive contributions from many explicit tasks and the quality or accuracy of that perception of enemy intent may vary with the number of explicit tasks accomplished.

A second consideration is the impact of implicit tasks on explicit tasks. The transcripts of command team staff make frequent references to gut feelings or implicit knowledge of task completion at satisfactory levels of confidence. It is possible that the completion of implicit tasks and the development of knowledge of enemy intent, a shared mental-model of enemy and friendly force disposition and capability, result in this subjective confidence. This is a meta-cognitive state, or more correctly meta-knowledge statement, because it indicates how the individual feels about the knowledge they have. As indicated below there are at least four basic states for meta-knowledge and knowledge and there is only one state in which certainty and confidence has any value.

Knowledge Status Meta-Knowledge	Accurate Perception	False Perception
Highly Confident	Good Knowledge and Accurate Assessment	Poor Knowledge Inaccurate Assessment
Low Confidence	Good Knowledge and Unsure Assessment	Poor Knowledge and Unsure Assessment

Table 1: Meta-knowledge and Knowledge

The top left-hand box on the table represents the situation where the command team knowledge is good and the command team is aware this is the case. The lower left hand box is where the command team has an accurate perception but has residual uncertainty about the quality of their assessment. It can be argued that the left hand side of the table is not problematic because at least the knowledge is accurate, even though the assessment of the certainty or confidence is not. The worst that may occur in cases of uncertainty is further searches for relevant information that would use

reconnaissance and sensor assets on the battlefield. Consider the right hand edge of the table, the lower condition when knowledge is poor and there is a high degree of uncertainty about the validity of the knowledge. Again it can be argued that this is an acceptable if unwanted state of affairs because the command team or user is motivated to improve their knowledge. The last state, where the user is confident about their knowledge but has a false perception of the current state is very problematic as actions may be taken in error. It is proposed that the socio-cognitive processes of command teams consist of elemental actions that promote basic situation awareness, team situation awareness and meta-situation awareness.

Basic situation awareness takes the forms of individual situation awareness identified by Endsley (2000) in the various reviews of her model, which can be graded to indicate basic perceptual awareness, comprehension awareness and projection level situation awareness. Team situation awareness would encompass a shared version of this mental-model and meta-situation awareness would be a qualitative assessment of the model at individual and team levels. The view that mental models have a critical role to play in team decision-making is widely accepted and has a long history in the academic literature, with work like that of Rouse, Cannon-Bowers, and Salas (1992) identifying a pivotal role for mental models.

Donald Rumsfeld originally classified various levels of meta-awareness in discussing known-knowns, the known-unknowns and the unknown-unknowns. Rumsfeld's definitions that are directed largely at intelligence seem to focus on the gaps in knowledge that are not identified as the critical issues in intelligence. It is likely that all battlefield knowledge is incomplete and uncertain with some of the skill of the command team in predicting the areas where additional knowledge is required and where uncertainty still exists. Often command teams have been asked to impose structure and form on the information in advance of action but more recently command team planning has evolved in to more fluid planning to aid sensor to shooter actions in unscripted use of force.

In addition to the explicit and implicit task dimensions it is clear that the dialogue between human and machine agents may exist at the level of a knowledge-based representation because the higher levels of knowledge use, outlined in many articles on knowledge-management, require the use of context to imbue the raw information with comprehensible value. This is significant in that expert human operators normally develop skills which produce a shift in skilled behaviour from knowledge-based, through rule-based and on to skill-based performance. Skill-based performance is normally equated with automaticity in information-processing and the potential use of implicit knowledge that is not easily recovered to conscious analysis. If machine-intelligence does not adapt or adjust the presentation of information as the user's needs change then it is likely to obstruct the development of advanced skill in the execution of the relevant tasks. One of the critical questions to consider is how sophisticated the machine intelligence needs to be because even rudimentary searching skill may be sufficient to identify critical associations and present them for further analysis to the human operator. Thus, it may be possible to mimic rule-based performance to achieve greater synergy between the expert human operator and machine, to improve combined performance on the relevant tasks.

Critical Issues of Tempo, Self-Synchronisation and Coherence

In the development of network enabled operations three factors have been identified as crucial tempo, self-synchronisation and coherence. Many of the basic issues were identified in Pigeau and McCann's (2000) edited collection of papers but more recent publications re-iterated these themes within the context of network-enabled operations.

It has been suggested that the network supported intellectual processes will be superior to and different from previous process structure. It is worth considering in abstract the plausibility of this view and its relationship to some of the evidence accrued from the transcript analysis of command team participants.

Tempo

Tempo has been treated synonymously with compression of the Observe, Orient, Decide and Act, so called OODA loop. Some commentators on command and control have emphasised tempo above all in command decision-making (Crabbe, 2000). Compression could take a number of forms and these changes in the current process might have logical consequences for the quality of decision-making performance. Consider first step omissions in the targeting process where the OODA loop becomes the ODA (Observe, Decide and Act) loop. Omitting the orienting process may be possible because the knowledge preparation in advance and synchronous to the targeting process is available to result in deletion of a process step. This makes certain assumptions about the currently available information with regard to its integrity and availability that currently cannot be supported on the battlefield.

Consider the possibility of parallel or near-parallel processing of the available information in real-time to accomplish successive tasks simultaneously. This assumes that any one task has no dependencies on others tasks or their outcomes. For example, sequential task management may reveal strengths and weaknesses in the data that shape the processing of related information in sequential task structure, in a manner that is no longer possible in parallel task architectures.

The major problem is that there are currently no accurate models of command team performance and task structure that adequately address this set of issues. The command team transcripts are suggestive of a normal or more frequent set of task inter-dependencies and benefits from sequential task structure, while there is no comparison for parallel command team performance. It is known that time stress has a negative impact on the quality of decision-making (Lehner, Seyed-Soloforough, O'Connor, Sak, and Mullin, 1997).

Self-Synchronisation

The delivery of information to users from a network should ensure that adaptation of plans to meet the conditions that occurs. The quality and detail of that information in turn should enable distributed re-planning and execution to occur with the distributed teams in possession of adequate knowledge to combine an understanding of

commander's intent and prevailing conditions to take effective decisions. The critical importance of command intent in military command and control has been emphasised by Shattuck and Woods (2000). The presumption is that if uncertainty and ambiguity occurs then the degree of error is too small to have any significant impact on the operational plan. The availability of the communications network is effectively imbuing the distributed staff with confidence in their course of action.

Network Enabled Operations Issues

The network enables the means to communicate quickly and cheaply to anyone who has access. However, the transcripts from command teams suggest that the traffic, the content and veracity of the data need to be carefully monitored. The availability of content can become readily result in information overload (see Freeman, Cohen and Serfaty, 1997). It has been argued that effective command and control is associated with simplicity and the minimum amount of information needed to meet the task requirements (Long, 2003). The quality of the content needs to be tagged to ensure that information users can interrogate with regard to the source and this is related to the time-stamping of information. In asynchronously updated information networks where the action required are highly dynamic and demand real-time response it is possible for actions to be taken on information that is out of date. Historical analysis of battlefield performance suggests that while single factors do not frequently result in failure the significant contribution from specific information sources is significant enough to generate concern. Friendly fire incidents, co-lateral damage and political concerns in warfare have complicated the process where international law applies to the method and consequence of action. It is conceivable that command team socio-cognitive work in pre-planning is intended to protect against these unforeseen consequences and produce a backbone of information that is accepted and used for major command team decisions. In simple terms the socio-cognitive work of the command team identifies and negates the impact of database errors.

It has been argued that networked information usage supports the innovation through openness of information sources. It is not clear that the interface currently available to the command team enables the user to adequately develop an image of the critical questions in the battlespace. It is likely that users faced with an interface that inhibits understanding will be more likely to rely on familiar methods and processes that represent easy cognitive challenges. Thus, innovation is less or more likely to flourish in networked information usage dependent on the ease with which information can be accessed and used. The available evidence suggests that the affordance of paper-based systems has not yet been achieved in electronic information systems because the interface tools to carry out the operations used on paper do not currently exist. There are significant steps to produce electronic maps that allow for hand annotation of force disposition and action, although the added value from these appears to be in communicating to others and not with regard to the command team functions.

Underpinning network-enabled operations is the argument that it is pervasive and comprehensive supporting access anytime and anywhere. This is again significant because gaps in network operation need to be managed and they need to be part of the operators awareness, to ensure that they do not become some of the unknown unknowns that Donald Rumsfeld refers to. The consequences of network failure in blue force tracking and potential fratricide in asymmetric conflicts seem to be

especially great. The nature of counter-insurgent operations in which joint-force responsibilities exist is especially prone to this type of issue as conflict in Afghanistan and more recently in Iraq suggests.

It has been suggested that networked sharing of information promotes dis-inhibition and linked to that it results in an equitable distribution of power. In military operations the use of network-enabled operations may be likely to create important issues with regard to the use of intent and this creates important responsibilities for command teams attempting to frame the intent in such a manner as to create robust communication of the intent and modification of specific actions around the intent, in response to battlefield conditions. The evidence available from the transcripts suggests that the exchange of information is more that just the mechanical distribution of rules and orders. This perspective on the use of information is supported by a number of papers in Pigeau and McCann's (2000) edited series.

The proposed development of network-enabled operations is based on simple principles that at first seem to be impossible to refute. Networked operations create opportunities for asynchronous communication, increased pace of actions and new types of operations, actions and tactics. The disintegration of knowledge management activities is likely to occur at all command levels and within levels of command, as the user relies upon the technology to mediate their exchanges with other team members explicitly or implicitly. The evidence from mediated communication overwhelmingly suggests that communications can degrade in unforeseen ways and give rise to distorted or biased perception, resulting from the presence or absence of transformations that occur through other patterns of interaction (Cook, Angus, and Campbell, 1999). It has also been argued that where groups face novel, unusual or unexpected decisions for which they are not cognitively prepared they are more likely to be subject to bias (Jones and Roelofsma, 2000). Artman (2000) has suggested that team situation assessment and awareness are predicated on the style of interaction between team members, which may in turn be influenced by technology. Thus, in telephone and face-to-face communication the processes of recovery and repair are more readily identified and instituted than in electronic communication. This observation, of problematic mediated communication, in conjunction with non-routine operational requirements may be critical.

It may the additional quality of communication sufficient to manage non-standard operations and the problematic nature of mediated communication that combine to produce ineffective performance. Incidents or failures where command errors can be written off as violation of organisational rules or communication issues often suggest that communication is subtly influenced by relatively trivial factors like the ease of communication, the costs of preparing communication, the latency of response and management of the exchange process.

Electronic mail is a good example of this in that it is asynchronous, leading to disjunctive exchanges, where the context of message preparation may not be easily re-created at receipt of the exchange. The latency of exchanges in e-mail is highly variable leading to uncertainty about the receipt, the interpretation and the need for repair. Finally, e-mail is generally considered to be a relaxed style of communication in many environments but military hierarchy may be equally influential in distorting this relaxed style to result in suppression of discordant messages, shortening of

communication into a terse style that requires elaborate interpretation skills, and given the risks associated overly cautious or overt in the expression of the content. Thus, mediated communication styles are frequently misinterpreted, provoke misunderstandings and significant more effort is subsequently devoted to crafting the message than accomplishing the joint task.

Antagonistic Interactions in Information Processing

In psychological theory the trade-off between speed and accuracy in performance is central to many tasks, even though there are deviations in relationship with regard to expertise and after training. The general form of the trade-off function is a negatively accelerating curve where the number of errors made is very high with fast responses and it decreases with increasing time spent on the decision making process. It is plausible to believe that a similar relationship exists with command decision-making such that a better quality of decision is made with increasing time spent on the decision. Again analysis of expertise suggests that expert decision-makers expend more effort on the analysis of the problem and situation assessment than they devote to later processes of selecting the response and planning action. This in turn supports the view that greater time devoted to making decisions and particularly with regard to the early stages establishing the current situation is critical to effective decision making. In addition, the richness of the decision-making should make significant contributions to flexibility of post decision-making response.

Given the emphasis on tempo within command decision-making it is likely that maintaining decision-making quality in the face of demands for faster responses that enabling the information assimilation process would provide significant dividends. The argument can be translated into situation awareness terms because it is preferable that decision-making is supported by good situation awareness and that means that decision-makers should notice, comprehend, and predict from their experience future actions. Thus, when a challenge is presented the decision-maker is capable of responding quickly and confidently with a high quality response. This improved situation awareness would be predicated on improved development of situation awareness, better maintenance of situation awareness, and better recovery of situation awareness after an unexpected series of events.

Networked Ability and Command Task Execution

Teams and Teams of Teams

A team is a group of individuals who collectively and collaboratively perform function(s) in order to achieve a specific, shared goal.

Individual roles

Individual have specified roles within a command team environment

There are a number of models that can be applied to the analysis of command teams related to information processing, communication and social psychological issues in

command teams (Thompson and Fine, 1999). However, in the limited number studies carried out on command teams there are no studies that provide adequate measures and analysis to differentiate between the competing hypotheses derived from these differing perspectives.

Command teams need to communicate using various media in order to construct an image of the battlespace that is then used to create effective decisions regarding courses of action. Different types of media have different properties with regard to their use in collaborative activities because some types of media afford more opportunity to synthesize solutions in a collaborative manner. Maps and whiteboards are good examples of media that afford and support collaborative activities in a simple and intelligible manner. For example, command team staff can use coloured pens to present alternative representations of the battlefield environment using maps and easily distinguish the different proposals to evaluate the most effective course of action.

Maps allow the user to create externally referenced memory aids that allow for a more sophisticated examination of the various proposals. It should be acknowledged that examination and evaluation of proposals in working memory requires data and operations, and it is generally accepted that these compete for information processing resources. Another significant problem in this regard is the large amounts of unfamiliar material use in some planning tasks because it is recognised that the frequency of exposure to material influences the recall of the information from memory.

It is clear that as the size of the command staff grows then the possibility of communicating all of the relevant information face-to-face, which is accepted to be the most effective method of communicating complex information, is much reduced. In addition, command teams may actually consist of distributed groups of individuals working on parts of the planning problem and the availability of actual collaborative workspaces is reduced, even though virtual workspaces may be provided.

Information Flow

One of the more obvious ways of examining team decision-making performance is in terms of patterns of information flow. The frequency of information exchange amongst participants, the types of exchange supported, or the functional properties of the exchange are all relevant patterns. It can be argued that those exchanging information frequently are critical to maintaining situation awareness because the quantity of information sent and received. However, information delivery can be redundantly encoded and frequency on its own may be misleading. It is possible that high value information is exchanged infrequently but it is highly critical to effective decision-making performance. Thus, an analysis of frequency and type of information provides a better image of communication costs and value. However, many analyses that counts and codes communication exchanges are frequently misleading because it is the context in which the communication exchange occurs that actually imbues the communication process with meaning. Thus, it can be argued that the count, code and goal (purpose) of information exchange are vital to correctly interpreting the significance of communication.

It might be argued that each type of variable is an index of different team decision-making processes. The frequency is an index of general situation awareness and of non-homogeneous information availability in the team. Uneven distribution of information in a team should tend to result in the initiation of communication to improve the shared mental-model. The type of the communication reflects the functional state of the team in relation to the task more directly because communication categorisation will reflect the goals of the command team at that point in time. Where uncertainty exists questions will be more frequent and in effective teams unsolicited information will be provided by team members in response to perceived need for information or clarification. The functional properties of the exchanges will often reflect broader aims and goals for the command team at the time of analysis with the phase of developing situation awareness, maintaining situation awareness and repairing situation awareness noticeably different as the profile of communication at that period of time varies.

In theory, a more effective information dissemination and knowledge development process should change the profiles for the command teams exposed to them because the need for communication should change, as it does with experienced teams and when teams met novel problems. It is clear from discussions with commanders that the flow of information is important with regard to the context, the mission/campaign phase, the operational environment, and status of the on-going execution process and between individuals with different levels of task experience. Thus, it is important to distinguish between the different influences on communication patterns and shared-understanding to identify any patterns that are specific to the type of technology used to support command team performance.

Differences in Communication

There are likely to be two broad types of communication variation in command teams, static and dynamic. Dynamic changes will probably be driven by phasic changes in planning and execution or by events in the external environment, reported to the command team. Static changes will often be related to the role of the individuals within the command team and their functionality in supporting command decisions.

Thus, it is expected that in a some cases information exchanges between command team staff will be asymmetric, with some staff requesting information and others supplying the information. In other cases, the patterns will change on a moment to moment basis to address issues that are identified to problems that occur in planning or execution. Underlying the low-level events there should be trends or patterns which occur as phases of the command team function are completed.

The actual management of communication is an additional task and one that should impose more or less workload on the command team. The workload may depend on the success of the command team in predicting the likely course of events and the complexity and pace of events in the operational environment.

Purpose of Command Decision Making

Command teams aim to perform many different functions and the following list for consideration is not meant to be an exhaustive list of the potential functions. The list below gives some indication of the diversity and the subtly of the tasks required of command teams. Research has suggested that intra-team feedback may be vital to the development of effective team decision-making because it appears to contribute to improvements in subsequent decision-making performance (Rasker, Post, and Schraagen, 2000). This finding suggests that communication, shared mental-models and team situation awareness are significantly influenced by patterns of communication, underlining the importance of secondary activities associated with command teams.

The idea that a command team's behaviour has an underlying socio-cognitive structure and that influences the effectiveness of decision-making performance is not new but it has found favour in recent years (Sonnenwald and Pierce, 2000). Sonnenwald and Pierce (2000) suggested that information behaviour in dynamic work contexts has evolved to provide shared situation awareness even in situations where the interpretation of information is contested between participants. The underlying purpose of the command team is assumed to be the critical evaluation of the current interpretation of the available information and a study of both social and cognitive processes are required to fully understand the process.

Evaluation of Information

Information Low or Missing

Identifies a lack of information available at time, or available due to technology. Includes comments on what may prove more effective. Need info that haven't got.

Evaluation and projection

Evaluation and projection of information and intelligence, includes continuous monitoring and weighing up the information etc.

Evaluation

There is a process of evaluation and risk assessment (calculation) of critical elements including finding a balance between these factors.

Command teams need to receive and assimilate information into a command team mental model. Often the process is challenging because of the quantity of information and the need to prioritise the information processing resources to make use of the most pertinent information. However, in military decision-making there are often residual levels of uncertainty and information received may contain false information that is intended to deceive. The communication of information or recording of information will often afford an opportunity to critically evaluate the likely veracity of information, the significance of information and to integrate the information into a bigger image of the battlespace.

Generating Questions

Questions

Questions are asked during decision-making process (may assist to develop a mental model). Questions address the comprehension, development, projection/prediction and evaluation/assessment and monitoring of a situation.

The information received may or may not integrate smoothly into the currently available information. Thus, anomalous information will generate questions with regard to the current working hypothesis and the types of information needed to support the current expectations. Thus, one of the significant functions of command team is to generate requests for information, battlefield sensing or intelligence that can qualify the current interpretation.

Cross-Referencing Information

Command teams share information in a manner that allows an integrated image of the battlespace environment to be produced. The cross-referencing of information is critical to the process of developing corroborative support for the current interpretations and the development of a course of action.

Identifying Critical Decisions

Factors: Critical

Critical decisions are generated for consideration by the command team (addressed by a critical issue question).

Factors: Other Factors

Comments collected on other influential factors that could be addressed perhaps by technology or appropriate information (not always addressed as an influential/critical question).

Critical Information

Comments were often noted on the critical pieces of information required to make an effective decision.

The process of working with the relevant information is not only to allow the command team to answer critical questions but in order to develop new questions that need to be posed against the available information. It is possible to develop a standard set of questions posed against plans and courses of actions, which will not satisfy all circumstances. Thus, there will be issues that need to be resolved in operations outside the normal set of actions, the opposing forces may be different from those normally considered, the operational environment and the capability of the opposing forces may be different from those normally encountered. There are clearly a myriad of reasons why operations need to be modified to match the prevailing requirement and there are clearly reasons why a standard approach to the line of reasoning will fail. This discovery of questions by the doing of the task is not unique to planning but occurs in many cognitively complex task where the information worked on is complex and the analysis applied is cognitively challenging.

Generating a Schedule of Expected Events

Evaluation & Projection

Evaluation and projection of information/intelligence, includes continuous monitoring and weighing up the information to cross check with expectations.

The production of a framework for the use of resources, the timing of events and their spatial location, is central to military planning. The work carried out accomplishing the construction of the schedule implicitly contributes to the development of an effective shared mental-model of the battlespace across the command team. The joint cognitive model is a critical by-product but not an explicit goal of the command team activities. The development of the joint cognitive model enables the command team to

carry out faster decision-making cycles in response to most of the future challenges by enabling the command team to propose and evaluate decisions and take action, without further observations/orienting.

Analysing Feedback on Decisions

Feedback on Decision Making
Comments were frequently made on the usefulness of feedback on decisions made.

The command team will normally absorb the outcomes associated with their executed plans and incorporate the knowledge of the outcomes into future decision-making. It is important to note that command teams need to evaluate the decisions they take, the pattern of information they based the decision on and the process that was used to extract and process the relevant information. While it is unlikely that the process can be adapted on a case-by-case basis the quality of the decision-making and the assumptions used to ensure critical thinking. The danger is that decision-making fails to take account of underpinning assumptions that do not apply in the current operational environment for political, legal or military reasons.

Segmentation of Issues in Command and Control

In the analysis of the transcripts it was possible to identify critical clusters of comments with a similar or related theme. For example, comments on information and knowledge, battlespace planning and communication were identified as potential clusters of related information. The frequency and the sub-topic structure within the transcripts allowed for a deeper analysis of the command staff's expressed requirements and concerns. The summarised issues are noted below.

Information and Knowledge

The use of information in a command and control environment is a significant skill that must be acquired, developed and maintained. Command teams need to review the sources of information, the utility of the information and assess comprehensiveness of the information available prior to making decisions. This skill in assessing knowledge, which has been referred to in the literature as meta-knowledge, may not be expressed overtly or explicitly. Many commanders make reference to gut instinct or feelings for information available. This suggests that the quality of the information and knowledge is stimulating a mechanism that makes use of implicit cognitive mechanisms for determining the overall value of the information and the knowledge derived from it.

Implicit cognition may play a significant part in drawing attention to transitional states when the pattern of information and knowledge reaches critical states or indicates critical events. For example, implicit cognition may be used to assess deception operations and to infer that the information received is intended to misdirect attention. Implicit cognition may also be used to infer when adequate preparation has been carried out to prepare the decision-makers for key decisions because the level of

understanding is adequate. Another role for implicit cognition may be in tracing transitions when plans or the actions of adversaries depart significantly from that expected.

Most analyses of decision-making indicate that decision-makers faced with complex decisions attempt to match experience onto the currently available information in order to solve problems. This process of pattern matching is unlikely to be comprehensive or completely systematic in terms of matching up all the relevant cues from experience with that currently presented. Thus, it seems likely that decision-makers will rely upon a sensed level of match that depends on gut instinct or implicit cognition. Similarly in evaluating the proposed course of actions it is likely that matching will occur in this manner because a detailed systematic analysis is not likely to improve the individuals understanding. If one accepts this argument then it is likely that a summarised account of the problem in some narrative form would be useful for communicating commander's intent and for ensuring an effective shared mental-model among command team staff.

Battlespace Planning

Shared Understanding

There were a number of comments on a shared understanding, a potential mental model, with possible ways in which a shared understanding can be improved upon and used.

The comments on battlespace planning extracted from the transcripts addressed two major sub-themes, the products of the battlespace discussions and the processes used to create the necessary products. It is argued that command staff process has generally evolved and adapted in response to new technology but that the socio-cognitive work associated with the process is the critical element of task, which may be resistant to certain types of technological innovation.

It is argued that battlespace planning is large focussed on two critical socio-cognitive processes that are implicitly supported by the cognitive work of the command environment these are the development of a mental model and situation awareness. For both of these socio-cognitive resources there is a set of processes to ensure that the mental-model and the situation awareness support adequate decision-making. The cognitive work of the command team must support development, maintenance, repair, analysis, evaluation and understanding of the current situation awareness and the relevant mental model. Situation awareness can be differentiated from the mental model in that it is a static representation of the current situation assessment and the mental model is a dynamic model of the past, current and future environment that informs decision-making.

Each of the six processes for supporting SA and the team mental model are likely to require slightly different information manipulation and visualisation tools. In studies of distributed simulation management, which have many similar issues to those of command and control, the process of planning and execution of the simulation require different tools and visualisation. It has been observed that tools that are adequate for

establishing a micro-world scenario are not adequate to repair and adjust the same microworld in real-time when the scenario direction deviates from that desired. For example, the development of a force disposition model is very different from characterising a dynamic threat and the questions posed required a different method of interacting with the database of available information. The aim of the current research to identify core elements of the overall process that can be enabled and it is likely that situation assessment is one of the basic processes.

Communication

Exchange of Information

Communicating and passing on information within the command team and to external groups. The importance of exchange was particularly with regard to the communication of intent, both within and out of the team.

Communication/Exchange: Aids

Analysis of the transcripts suggested that aids and methods to assist in effective communication of decision-making, situation awareness (assessments) and intent.

The command and control process, within the command team and between the command team and others depends on effective communication. The introduction of new technology to support the command team process must address this requirement and at the same time support the structuring of command team activity to develop an effective mental model of the battlespace and the task requirements of that virtual model.

Summary

In the introduction to this report it was suggested that command teams worked on explicit processes and carried out implicit processes that further supported potential command team actions by developing capability. The development of the plan, an explicit task, has a task grammar that stimulates other activities, such as prioritisation of issues, development of evaluation of the proposed plan, cross-referencing of information and evaluation of information quality. The task grammar and associated activities contribute to the quality of the communication activities, the battlespace planning and the meta-knowledge about the current situation awareness/shared mental-model. Thus, the actions of the command team distribute knowledge, qualify the plan and develop a level of confidence, with regard to success, which should terminate planning activities in a social and cognitive sense.

The introduction of new technology into this environment should support the same explicit and implicit products of the command teamwork and tasks, even though the processes change. The assessment of success would not use the same process measures that would clearly change between conditions with and without new technology. Instead it would need to use outcome measures related the products of

superior knowledge and capability to apply knowledge. The final quality of the decision has significance for actual decision makers but it would frequently be contaminated with individual knowledge and experience. Thus, the final decision that it might be argued is the critical outcome is not necessarily the valid or unbiased measure of command team performance.

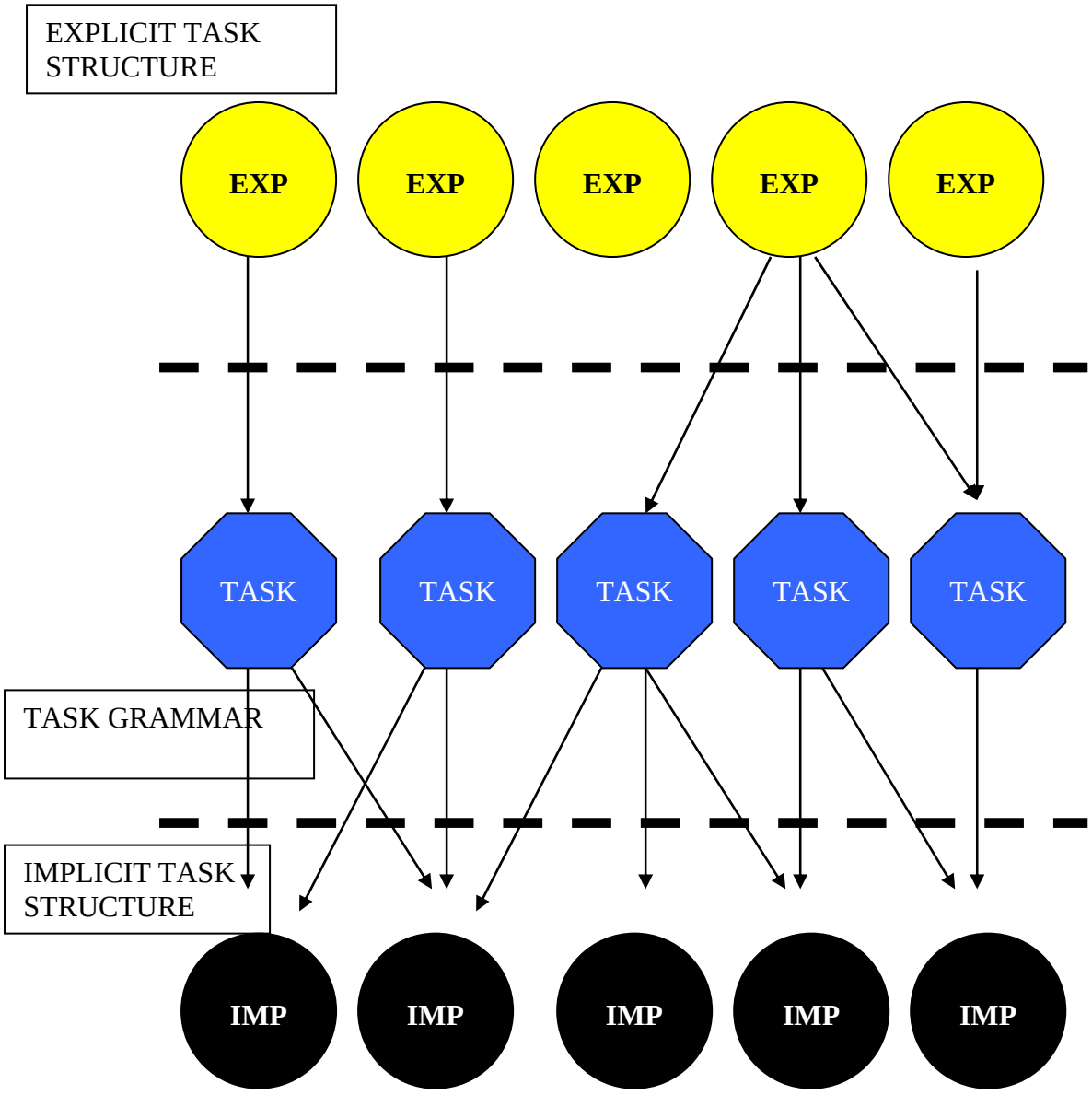

Table 2: Relationship between task grammar/syntax and explicit and implicit tasks.

In the figure above it is proposed that the explicit task structure, which would include estimates and schedules, supports implicit tasks, such as the creation of the shared mental-model, via specific task grammar and socio-cognitive interactions, such as information exchange between those responsible for intelligence and planning functions in the command team.

Technology, and the use of mediation, via agents or knowledge stores would change this underlying task grammar and modify the quality of explicit or implicit task-

related outcomes. For example, shared situation awareness or the quality of the shared mental-model or the awareness of the underlying assumptions could be inferior or superior with mediation. It is likely that a shift towards mediated communication with its reduced opportunities and mechanisms for repair and recovery, would be detrimental to shared knowledge if care was not taken in the design. There are historical examples of specialist teams of decision makers producing competing and antagonistic representations of the problem domain without an awareness of this occurring. Thus, it is argued that command team processes evolve to create synergy between action and function, with explicit or implicit goals to shape the evolutionary process.

To evaluate empirically the impact of enabling technology on simulated command team decision-making it is necessary to measure the process and outcomes of decision-making within a framework such as that proposed. It is recommended that techniques and methods from a multi-disciplinary approach be used to determine the efficacy of the intervention. The critical measures for assessment should be with regard to the assimilation and use of knowledge within a time-constrained task where information overload can occur, preventing knowledge development. The critical nature of the cognitive challenges in high-level command and control decision-making had been identified earlier (Cook, Stapleton, and Artman, 2000) but the relationship between these challenges and the specific task structure had not been examined in detail. Even though this analysis represents an analysis of retrospective accounts of command practice it has been combined with experienced and judgement of command environments of the analysts to assess the credibility of the perception, in terms of cognitive demands. In the final analysis, this is only intended as a prelude to a more detailed and sophisticated analysis of performance using empirical methods, which should provide an accurate assessment of the cognitive challenges and the means to overcome them. It is important to produce flexibility because knowledge management strategies for decision-making can actually increase the possibility of organisational rigidity (Builder, Banks, and Nordin, 1999).

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